

Study of mismatched microstrip termination in warm ionized plasma medium

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Abstract : Study of radiation properties of mismatched microstrip termination is carried out in warm ionized electron plasma medium. Linearised hydrodynamic theory coupled with vector wave technique is used to investigate radiation patterns and radiated power of a microstrip mismatched termination in one component electron plasma media for different plasma to source frequencies. These properties are used to compare the performance of an open circuit discontinuity with those of matched microstrip termination. Matched terminations are found more suitable for applications at higher frequencies than an open circuit discontinuity in the plasma medium though in free space they are less suitable.

Keywords : Mismatched termination, open circuit discontinuity, matched microstrip termination, ionised plasma

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1. Introduction

Microstrip antenna has proven to be an effective, light weight and quite inexpensive radiator for aerospace vehicles [1]. Many workers have reported radiation properties of different microstrip radiators in free space [2–4]. Metallic and dielectric losses, breakdown effect at higher power level and radiations from discontinuities however limits the application of a microstrip line structure over the ground plane [5]. Radiations from microstrip discontinuities become quite dominant at microwave frequencies and hence become major limiting factor. Hence it is always necessary to control them somehow. Radiations from an open circuit microstrip discontinuities are investigated recently [6] in an ionized plasma medium of infinite thickness. Radiations from a mismatched termination in an ionized plasma medium are investigated in this communication. Using these relations, performance of two other type of discontinuities viz. a matched microstrip termination and

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an open circuit microstrip termination are investigated in free space as well as in ionized hot plasma medium.

2. Results and discussions

In strip line structure, field does not lie uniformly inbetween the conducting patch and the ground plane but some fringe fields leak in the air near the edges of the strip. Dielectric polarization beneath the strip takes place which gives rise to the polarization current in addition to the already existing strip current [5]. Considering both these currents together, radiation patterns and radiated power by a mismatched termination are obtained for different plasma to source frequencies (ω_p / ω).

Current distribution and radiation patterns :

With the presence of an actual ionized plasma medium, effective permittivity of structure changes marginally in comparison to the effective permittivity in free space and hence resonance frequency also changes marginally [7]. It is found that percent deviation in frequency is about 0.003% in the presence of an ionized plasma media of infinite thickness which does not effect predicted results seriously.

The geometry and coordinate system of a mismatched microstrip termination is shown in Figure 1.

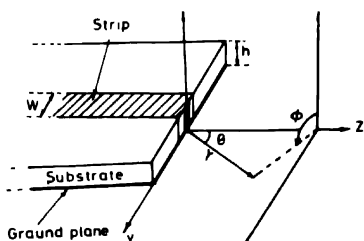


Figure 1(a). Geometry and coordinate system of microstrip mismatched termination

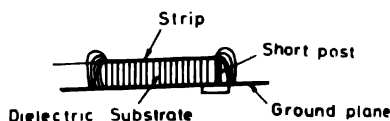


Figure 1(b). Leakage of electric field in space

A stripline above the ground plane is located along the z-axis of the coordinate system. The thickness of the dielectric substrate is considered to be " h ", width of strip " w ", relative permeability and permittivity $\mu_r = 1$ and $\epsilon_r > 1$ respectively.

It is considered here that the termination mismatches the strip. Far fields are obtained by considering a magnetic current density along with a perfect electric current condition.

For stripline configuration, the integration to find electric field using vector potential is carried out over a cross section which gives a combination of currents formed by polarization current (along x-axis) and a strip current (along z-axis).

Let the strip current be

$$I_s = I_0(e^{-jkz} + Re^{jkz}) \quad (1)$$

where $k = \frac{2\pi}{\lambda_0} \sqrt{\epsilon_{\text{eff}}}$

$$R = |R| e^{j\psi}$$

λ_0 is the wavelength in free space, ϵ_{eff} is the effective dielectric constant of substrate material, $|R|$ is the reflection coefficient at the end of the line and its limiting value lies in between 0 and 1, and ψ is the phase angle between the incident wave and the reflected wave.

Assuming current amplitude is to be constant across the strip line, the surface current density in z-direction for end fed line will become

$$J_s = I_s \exp(j\omega t) \hat{i}_z \quad (2)$$

The polarization current density in x-direction will be

$$J_p = \left(\frac{\epsilon^* - 1}{\epsilon^*} 2h \frac{\partial I_s}{\partial z} \right) \exp(j\omega t) \hat{i}_z \quad (3)$$

where \hat{i}_x and \hat{i}_z are unit vectors in the x and z direction respectively and ϵ^* is the actual dielectric constant of the substrate material.

Considering the presence of both these currents together and following the method of [8], the expressions for the radiation patterns are obtained in electromagnetic mode as well as in electroacoustic mode. These expressions are :

(i) In electromagnetic mode :

$$E_\theta = \frac{j60hw\beta_0 I_0}{\epsilon^* r} e^{j(\omega t - \beta_r r)} \left[\frac{\Lambda \sqrt{\epsilon} (\epsilon^* - \cos^2 \theta) + (\epsilon^* \Lambda^2 - \epsilon) \cos \theta}{(\epsilon - \Lambda^2 \cos^2 \theta)} + R \frac{(\epsilon^* \Lambda^2 - \epsilon) \cos \theta - \Lambda \sqrt{\epsilon} (\epsilon^* - \cos^2 \theta)}{(\epsilon - \Lambda^2 \cos^2 \theta)} \right] X_e \cos \phi \quad (4)$$

$$E_\phi = \frac{j60hw\beta_0 I_0}{\epsilon^* r} e^{j(\omega t - \beta_r r)} \left[\frac{\epsilon^* \Lambda \cos \theta - \sqrt{\epsilon}}{(\sqrt{\epsilon} - \Lambda \cos \theta)} - R \frac{\sqrt{\epsilon} - \epsilon^* \Lambda \cos \theta}{(\sqrt{\epsilon} + \Lambda \cos \theta)} \right] X_e \sin \phi \quad (5)$$

where $X_e = \frac{\sin(\beta_e (w/2) \sin \theta \sin \phi)}{(\beta_e (w/2) \sin \theta \sin \phi)} \exp[j(\beta_e (w/2) \sin \theta \sin \phi)]$

$$\beta_e = \frac{2\pi}{\lambda_0} \Lambda : \text{where } \beta_e \text{ is the propagation constant in electromagnetic mode}$$

$$\Lambda = \sqrt{1 - \omega_p^2 / \omega^2}$$

$$\omega_p = \text{angular plasma frequency (sec}^{-1}) \quad \omega = \text{angular source frequency (sec}^{-1})$$

$$\beta_0 = \text{propagation constant in free space (radian / m)}$$

(ii) In electroacoustic mode :

$$E_p = \frac{wh\beta_p \omega_p^2 I_0}{2\pi r \omega (\omega^2 - \omega_p^2) \epsilon^*} \left[\frac{\beta_p (\cos \theta - \sin \theta \cos \phi) - k'/\epsilon^*}{(k' - \beta_p \cos \theta)} - R \frac{k'/\epsilon^* - \beta_p (\sin \theta \cos \phi - \cos \theta)}{(k' + \beta_p \cos \theta)} \right] X_p e^{j(\omega' - \beta_p r)} \quad (6)$$

where
$$X_p = \frac{\sin(\beta_p (w/2) \sin \theta \sin \phi)}{\beta_p (w/2) \sin \theta \sin \phi} \exp \left[j \left(\beta_p (w/2) \sin \theta \sin \phi \right) \right]$$

and $\beta_p = (c/v_0) \beta_0 \Lambda$ is the propagation constant in plasma mode.

These value of $|E_\theta|$, $|E_\phi|$ and $|E_r|$ are computed and plotted in Figures 2, 3 and 4 for two different values of plasma to source frequency. Computations are carried out for $h = 0.158$ cm, $w = 0.471$ cm, $\epsilon = 2.31$, $\epsilon^* = 3.0$, operation frequency = 1.2 GHz, $|R| = 0.7$ and $\psi = \pi$

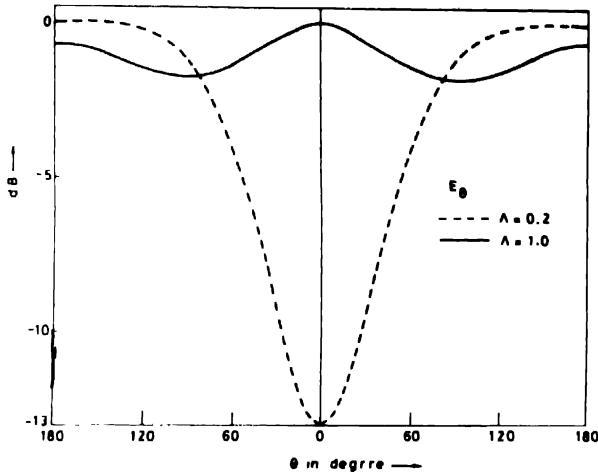


Figure 2. $|E_\theta|$ component of radiation pattern for $\Lambda = 1.0$ and 0.2 .

$|E_\theta|$ patterns in free space ($\Lambda = 1.0$) are almost uniform. Radiation intensity in the end fire direction ($\theta = 0^\circ$) is slightly more than the radiation intensity in the broadside direction ($\theta = 90^\circ$). On increasing plasma to source frequency ($\Lambda = 0.2$), radiation pattern modifies drastically and direction of maximum intensity shifts from ($\theta = 0^\circ$) to ($\theta = 180^\circ$) direction and a minimum appears at ($\theta = 0^\circ$). Almost similar behaviour appears for $|E_\phi|$ patterns. These patterns in the free space ($\Lambda = 1.0$) are almost symmetric in all the four quadrants, but for a higher plasma to source frequency value ($\Lambda = 0.2$), the 3dB

beamwidth in ($\theta = 0^\circ$) direction is much smaller than in ($\theta = 180^\circ$) direction as shown in Table 1.

Table 1. 3dB beamwidth in θ and ϕ planes for $\Lambda = 1.0$ and $\Lambda = 0.2$.

E_θ				E_ϕ			
Free Space ($\Lambda = 1.0$)		Plasma ($\Lambda = 0.2$)		Free Space ($\Lambda = 1.0$)		Plasma ($\Lambda = 0.2$)	
3dB Front direction	3dB Back direction	3dB Front direction	3dB Back direction	3dB Front direction	3dB Back direction	3dB Front direction	3dB Back direction
108°	116°	0°	120°	104°	106°	82°	114°

$|E_\rho|$ radiation patterns indicate that only one lobe appears in the 50° to 60° range. On substituting $|R| = 1$ and $\psi = \pi$ all the expressions obtained for mismatched microstrip termination reduce immediately to those of open circuit microstrip discontinuity [6]. Similarly on substituting $|R| = 0$ and $\psi = \pi$, expressions for microstrip matched termination can be obtained [8].

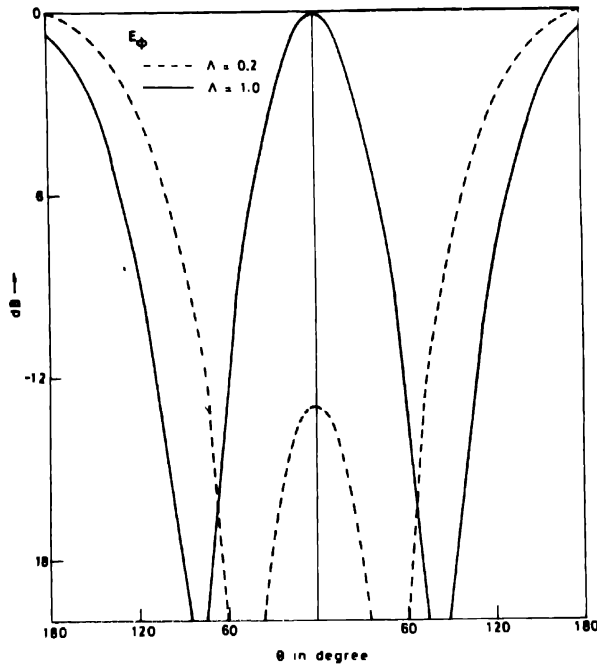


Figure 3. $|E_\phi|$ component of radiation pattern for $\Lambda = 1.0$ and 0.2 .

Radiated Power :

The power radiated by the microstrip mismatched termination through upper half space is obtained by using Poynting vector. For different values of plasma to source

frequencies, expressions for radiated power are obtained by using the method of [8]. These expressions are :

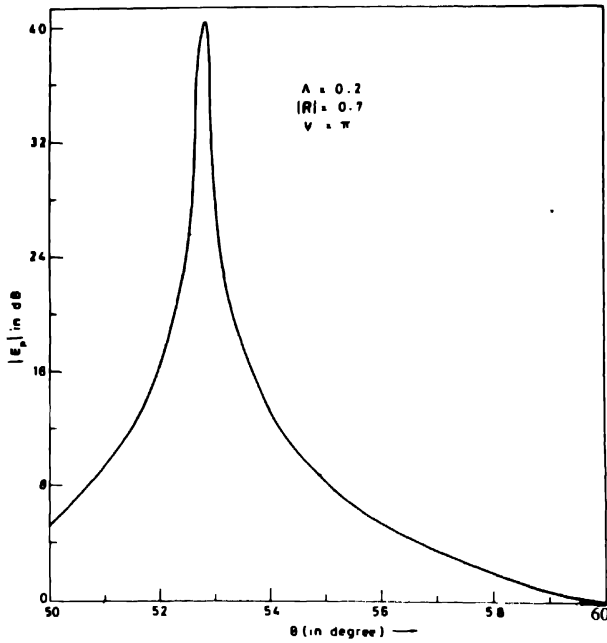


Figure 4. $|E_p|$ component of radiation pattern for $\Lambda = 0.2$.

(i) For electromagnetic mode :

$$P_e = \frac{15h^2w^2\beta_0^2\Lambda I_0^2}{\pi\epsilon^{*2}} \int_{-\pi/2}^{+\pi/2} \int_0^\pi \left[|S_1|^2 \cos^2 \phi + |S_2|^2 \cos^2 \phi \right] \chi_e^2 \sin \theta d\theta d\phi \quad (7)$$

where

$$S_1 = \left[\frac{\Lambda \sqrt{\epsilon}(\epsilon^* - \cos^2 \theta) + (\epsilon^* \Lambda^2 - \epsilon) \cos \theta}{(\epsilon - \Lambda^2 \cos^2 \theta)} + R \frac{(\epsilon^* \Lambda^2 - \epsilon) \cos \theta - \Lambda \sqrt{\epsilon}(\epsilon^* - \cos^2 \theta)}{(\epsilon - \Lambda^2 \cos^2 \theta)} \right]$$

and

$$S_2 = \left[\frac{\epsilon^* \Lambda \cos \theta - \sqrt{\epsilon}}{(\sqrt{\epsilon} - \Lambda \cos \theta)} - R \frac{\sqrt{\epsilon} + \epsilon^* \Lambda \cos \theta}{(\sqrt{\epsilon} - \Lambda \cos \theta)} \right]$$

and the radiation resistance in electromagnetic mode R_e can be defined as

$$R_e = 2P_e / I_0^2 \quad (8)$$

(ii) For electroacoustic mode :

$$P_p = \frac{mk^2\omega^2\beta_p\omega_p^4I_0^2}{8\pi^2e^2n_0\omega(\omega^2-\omega_p^2)} \int_{-\pi/2}^{+\pi/2} \int_0^\pi \left[\frac{\beta_p(\cos\theta - \sin\theta\cos\phi) - k'/\epsilon^*}{(k' - \beta_p\cos\theta)} - R \frac{k'/\epsilon^* - \beta_p(\sin\theta\cos\phi - \cos\theta)}{(k' + \beta_p\cos\theta)} \right] X_p^2 \sin\theta d\theta d\phi \quad (9)$$

and the radiation resistance in plasma mode R_p can be defined as

$$R_p = 2P_p/I_0^2 \quad (10)$$

These values of R_e and R_p are computed and plotted for different values of plasma to source frequencies in Figure 5. In the electromagnetic mode, power radiated in free space ($\Lambda = 1.0$)

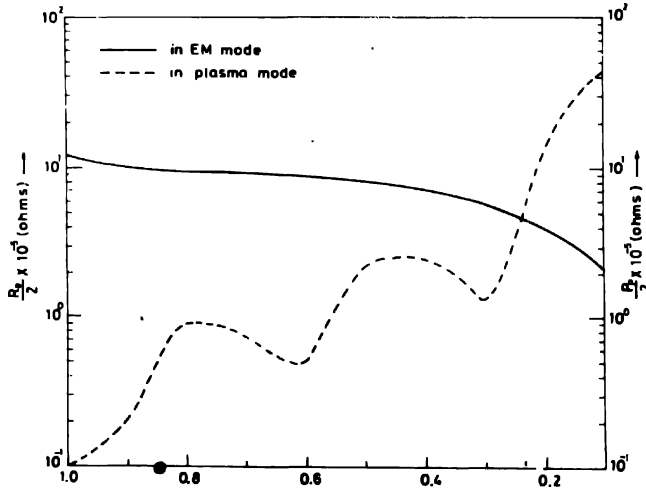


Figure 5. Variation of R_e and R_p with plasma parameter Λ

is maximum but decreases on increasing plasma to source frequency. On the other hand, plasma mode field patterns give a quasi periodic pattern. Initially, radiated power in plasma mode is less than the radiated power in electromagnetic mode but it over takes inbetween the range $\Lambda = 0$ to 0.25.

During the voyage in the space, aerospace vehicle interacts with plasma media and radiates electroacoustic waves in addition to the usual electromagnetic waves. Presence of the electroacoustic wave is mainly responsibly for such variation in this plasma media.

It is evident from the expressions of radiated power that they are a function of reflection coefficient. The variations of radiated power in free space $\Lambda = 1$ or $(\omega_p/\omega = 0)$

and in plasma media ($0 < \omega_p / \omega < 1$) are presented for both electromagnetic mode and longitudinal plasma mode in Figure 6.

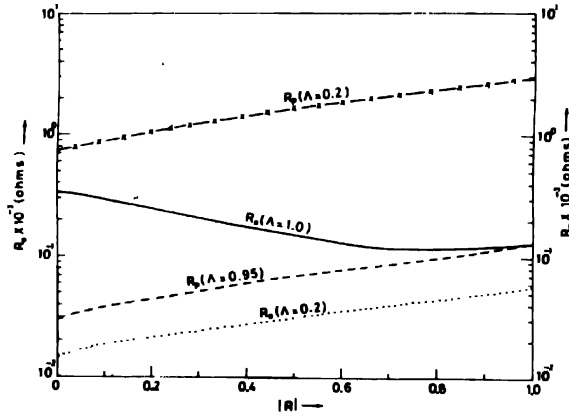


Figure 6. Variation of R_e and R_p with $|R|$ for $\Lambda = 1.0$ and 0.2 .

In free space ($\Lambda = 1.0$), radiated power in electromagnetic mode is maximum for $|R| = 0$ (matched termination). As mismatch increases, radiated power decrease and becomes minimum at $|R| = 0.8$. Thereafter it becomes almost uniform upto $R = 1$ (open circuit microstrip termination). On increasing the plasma to source frequency ($\Lambda = 0.2$), the radiated power by a matched termination becomes quite small in comparison to its free space value ($\Lambda = 1.0$). On increasing $|R|$ value, radiated power in electromagnetic mode increases continuously but it always remains less than the free space value even for an open circuit termination ($|R| = 1.0$).

In longitudinal plasma mode, radiated power at ($\Lambda = 0.2$) for a matched termination ($|R| = 0$) is low but increases continuously up to $|R| = 1$ (open circuit termination). The total power radiated ($P_e + P_p$) in free space ($P_p = 0$) is low for an open circuit termination.

3. Conclusions

Effect of the presence of plasma medium on the different discontinuities is observed here by considering different plasma to source frequency (ω_p / ω) values.

It can be concluded from the present study that for operation in free space, an open circuit discontinuity is better than a matched termination operating at very high frequencies. In the plasma media, matched termination is better than an open circuit discontinuity because total radiated power ($P_e + P_p$) is less for matched termination than an open ended termination. More radiations from any discontinuity causes less utility of that structure. Hence, a matched termination is suitable with an antenna in plasma media though open circuit discontinuity suits more in free space. A theoretical effort is made here in this

communication which requires experimental verification, though simulation of plasma media in laboratory is very difficult.

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